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8 Airport Road
Bethel, ME 04217, USA

What is the Lowest Cost Solution for Maximum Decarbonization of the On-Demand Power Sector while Maintaining Grid Reliability?

If the capacity factor is much below baseload (<80%) and natural gas prices are not at rock bottom, building new natural gas combined cycle generation is not the optimal solution.

September 2, 2024
William Strauss, PhD

By some metrics, the go-to solution for on-demand power that also lowers carbon emissions when compared to coal is the use of natural gas to run a combined cycle¹ (CC) generating unit.

However, natural gas (NG) is fossil fuel and, while CO₂ emissions per megawatt-hour (MWh) generated are lower for NG than coal, there are still significant CO₂ emissions from an NGCC power plant.

If the goal of policy is to lower CO₂ emissions in the power sector, the metric that should inform decision making should be based on the total investment and operating cost per avoided tonne of CO₂.

This white paper discusses this metric and will compare two options that provide on-demand dispatchable power:

- (1) Retire coal power plants and replace them with new natural gas combined cycle generating stations.
- (2) Modify existing pulverized coal power plants to use upgraded compatible fuel produced from renewing bioresources (commonly called pellet fuel) as a substitute for coal.

The prices of the fuels (natural gas and pellet fuel) matter when considering which of the two options above are optimal.

As will be shown later in this white paper, for Europe with high NG prices, option (2) is an unambiguously correct choice.

However, even with low natural gas prices in the US, there are plausible scenarios in which option (2) is still the best choice.

The US currently has very low natural gas prices. As Figure 1 on the following page shows, there is almost an order of magnitude difference between the US and Europe in terms of natural gas prices.

¹ See [HERE](#) for description.



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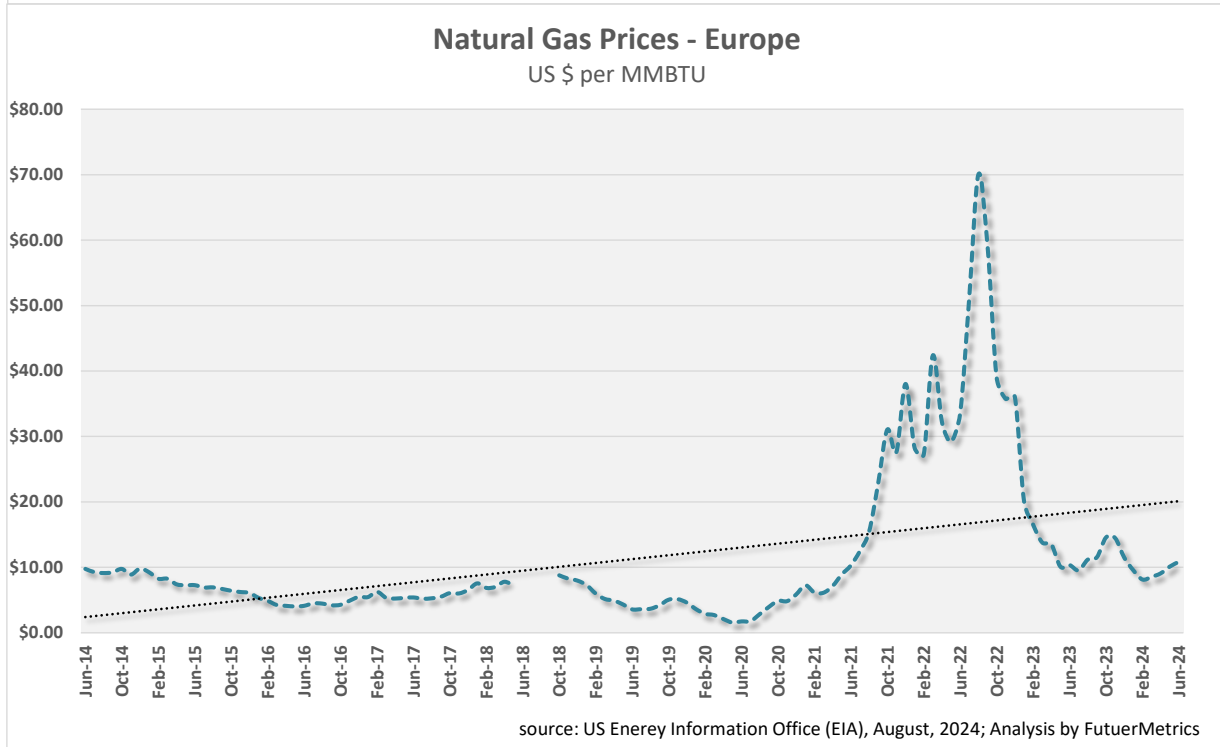
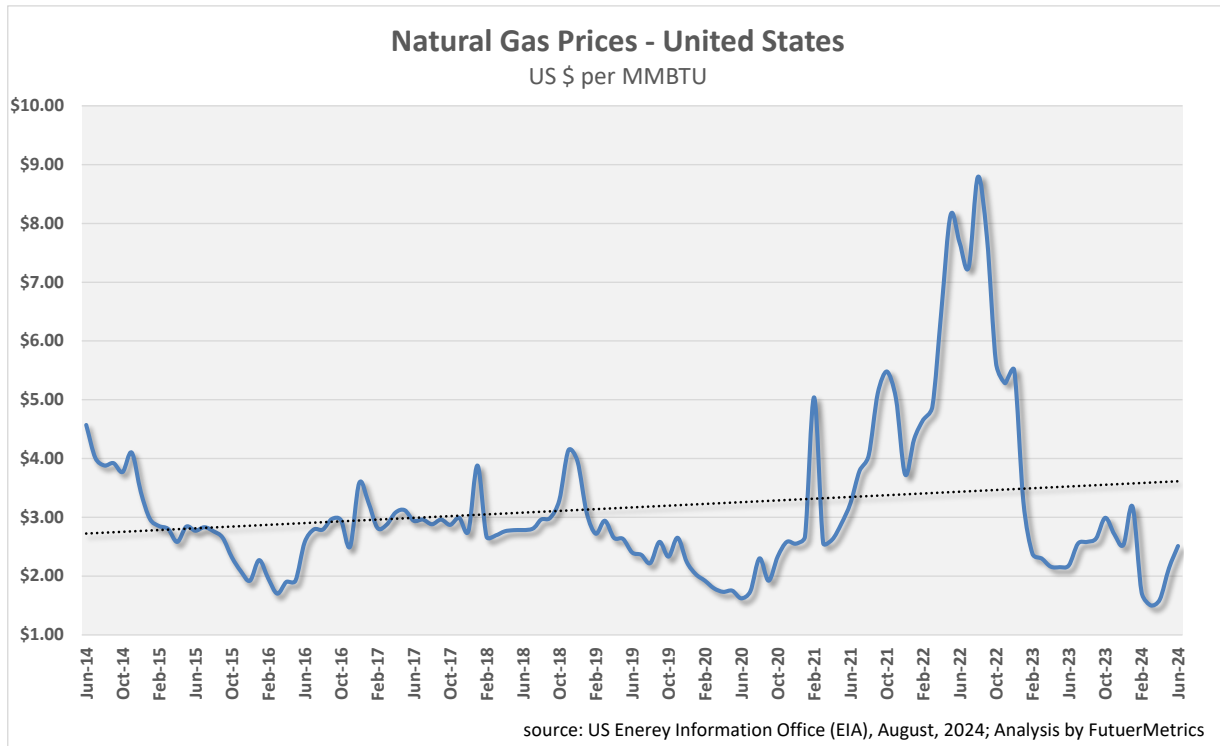


Figure 1 - Natural Gas Prices in Europe and the US



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Pellet fuel prices also matter in the decision-making analysis between options (1) and (2). Pellet fuel prices are reported by Argus for the spot market (see Figure 3 on the next page).

But most pellet fuel is traded under longer term contractual agreements. The exact proportions of imports traded under longer terms contract versus the spot market are not known exactly (and also the proportions fluctuate), but in general about 75% to 85% of all pellets traded into the UK and Europe for use in large scale power (or combined heat and power) generation are covered by long-term contracts. Long-term offtake agreement prices are unaffected by the supply and demand imbalances that create the higher volatility seen in the natural gas and spot pellet markets.

Figure 2 shows the estimated prices of pellets shipped into the UK. The trade data used to produce the analysis in Figure 2 includes imports under long-term agreement and spot deals. The UK is the world's largest importer of pellet fuel (see Table 1 below).

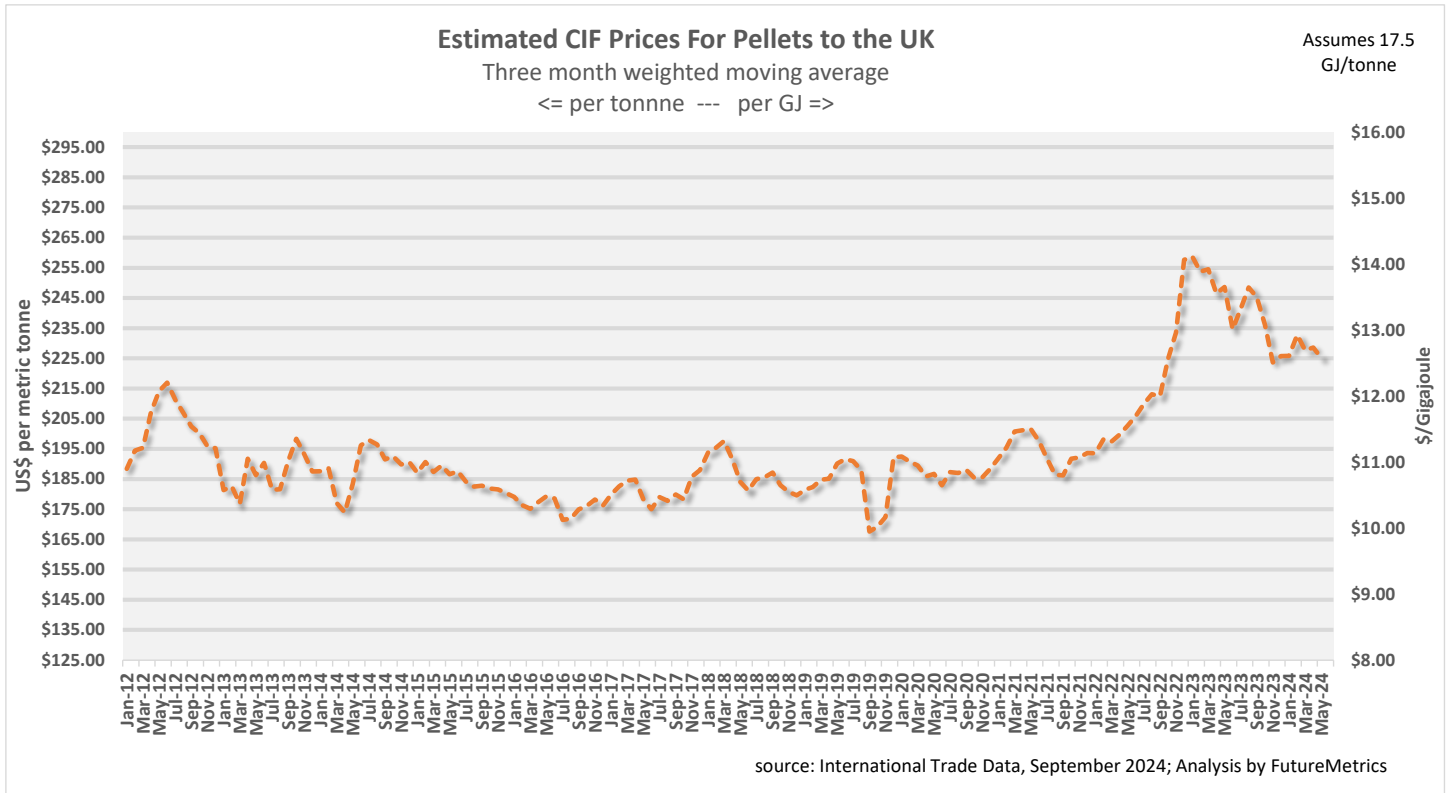


Figure 2 - Pellet Fuel Prices Delivered to the UK



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Pellet Imports Percent of all Imports (2023) (smaller importers not shown)	
UK	28.1%
Japan	23.3%
South Korea	16.3%
Denmark	9.2%
Italy (heating pellets)	9.1%
Netherlands	8.2%

source: Argus, Analysis by FutureMetrics

Table 1 - Major Pellet Importing Countries - 2023

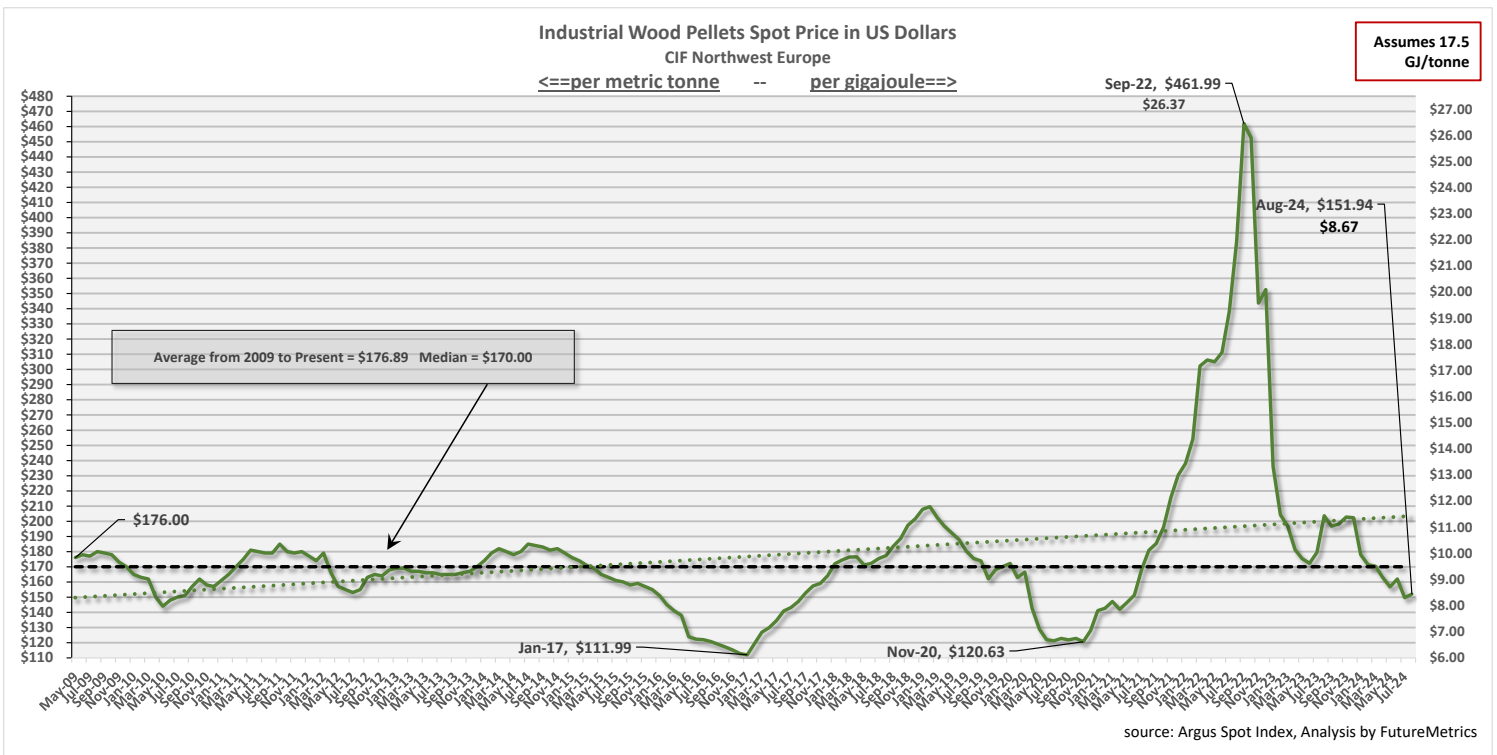


Figure 3 - Pellet Fuel Prices - Argus Spot



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Build New Natural Gas Plants or Convert Existing Pulverized Coal Plants to Use Wood Pellets?

This paper shows that when comparing the two scenarios, and when factoring in the reduction in CO₂ emissions from each option, **the solution that generally provides significantly better CO₂ reduction at a lower net monetary cost per avoided tonne is by repurposing existing pulverized coal power plants to run on industrial wood pellets².**

When measured by the net present value (NPV) of the total capital and operating costs per avoided tonne of CO₂, under most fuel costs and capacity factors, building new natural gas power plants is not the least costly way to mitigate carbon emissions while providing dispatchable generation.

Policymakers and utilities often see natural gas generation as a compromise between coal and the need for reliable on-demand low-carbon power. While NG is a fossil fuel, it does offer lower CO₂ emissions per MWh generated than coal³.

NG is perceived as a favorable solution for generating dispatchable power since the cost to build a new efficient combined cycle power plant is relatively low compared to nuclear and hydro, time to build is relatively short, and the cost of NG (in the US) is low.

Europe faces a very different set of conditions. NG prices are significantly higher, and the supply of NG is fraught with geopolitical risk.

If CO₂ reduction is the primary goal of policy, and therefore of the utility, the correct decision metric is not simply the capital cost for the plant and operating costs to make power. The correct decision metric should include a recognition of the impact that the project will have on CO₂ emissions.

The decision metric used in this analysis shows the cost of CO₂ mitigation as a function of the capital investment (CAPEX) and operating costs (OPEX) over time. The present value of the CAPEX and OPEX over a reasonable time span at an appropriate discount rate captures the value in current dollars of the total cost of the project. Comparing that number with the avoided CO₂ emissions realized from using a lower carbon emitting fuel versus coal yields a decision metric based on both financial and environmental concerns.

Calculating the lowest cost per avoided tonne of CO₂ combines good environmental policy with good business.

The alternative to building a new NGCC plant is to leverage existing power plants that are designed to efficiently combust pulverized coal (PC). Modern PC power plants can, with easy to deploy

² As is discussed in more detail later, this is if natural gas prices are above about \$4.00 per MMBTU, pellet prices are about \$185/tonne, and the power stations capacity factor is about 80%.

³ How much NG lowers CO₂ emissions versus coal depends on the type of coal it is being compared to and the efficiencies of the coal and natural gas power plants.



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modifications, substitute industrial wood pellets for coal⁴. The capital costs for the modification are significantly lower than the capital cost for a new NGCC plant and the construction time for modifications can be as short as a few months⁵. The operating costs, however, are higher. In terms of cost per unit of delivered energy, pellet fuel is costlier than NG.

But the carbon dioxide emissions reduction versus coal from a fully converted pulverized coal power plant using wood pellet fuel is significantly better than that from a new NGCC plant. The reduction in CO₂ emissions from NGCC versus modern coal power plant is about 57%⁶. The reduction in CO₂ emissions from a modern pulverized coal plant converted to use renewable bioresource derived wood pellets is 100%⁷.

The analysis that follows uses the default settings that are used in a FutureMetrics dashboard. The dashboard allows the user to change many of the critical assumptions that determine the results of the analysis. The dashboard can be opened by going to the FutureMetrics [website](#) and scrolling down the home page to the dashboard section or directly from this paper by clicking [HERE](#).

Figure 4 on the next page is a screenshot of the dashboard.

⁴ See several white papers at the [FutureMetrics website](#) on this topic.

⁵ Advances in producing economically competitive pellets that can be stored and handled like coal eliminate the need for a power plant to build the dry storage needed for typical “white” pellets. The cost of the dry storage is 50% or more of the total cost of modifying a PC power station. See the recent FutureMetrics paper and dashboard on this topic [HERE](#).

⁶ Based on EIA data. <https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11>

⁷ The supply chain carbon emission are not included for both NG and pellets. CO₂ emissions from the combustion component of wood pellets is 100% carbon neutral as long as the pellets are produced from feedstock that is derived from sustainable sources that are not depleting the net stock of carbon held across the forest landscape.



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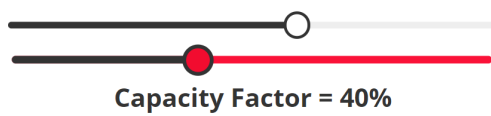
What is the Lowest Cost On-Demand Power Generation Solution for Avoiding Carbon Dioxide Pollution?

Dashboard Produced by
FutureMetrics
FutureMetrics Website

Compare building a new combined cycle natural gas fueled power unit with converting an existing pulverized coal power unit from coal to wood pellets.

+ Add scenario View all scenarios

Power Plant Size = 600 MWs



Capital Cost per kW of Capacity

Modification/Conversion of PC Coal Unit = \$280

Construction of New NGCC Unit = \$1250

O&M costs per kW-year

With Pellets = \$40

With NGCC = \$28

Fuel Costs

Pellets = \$185 per Tonne

NG = \$3.50 per MMBTU

40.0% Coal or Pellet Power Plant Efficiency

53.0% NGCC Power Plant Efficiency

18.00 Pellets GJ per Tonne = 5.28 MWh

25.00 Coal GJ per Tonne = 7.33 MWh

	Conversion to Pellets	Nat Gas Combined Cycle	Coal
Net Tonnes of CO2 Produced over 10 Years from Combustion	0 ?	28,806,469	84,471,429
Tonnes of CO2 Avoided over 10 Years	84,471,429	55,664,960	0
Percent Reduction vs. Coal	100.0%	65.9%	0%
NPV of Total Costs at a 6.0% Discount Rate over 10 Years	-\$2,020,135,348	-\$1,631,783,158	
NPV of the Cost per Avoided Tonne of CO2 ==>	\$23.92	\$29.31	

NPV Parameters

6.0% Discount Rate 10 Term in Years

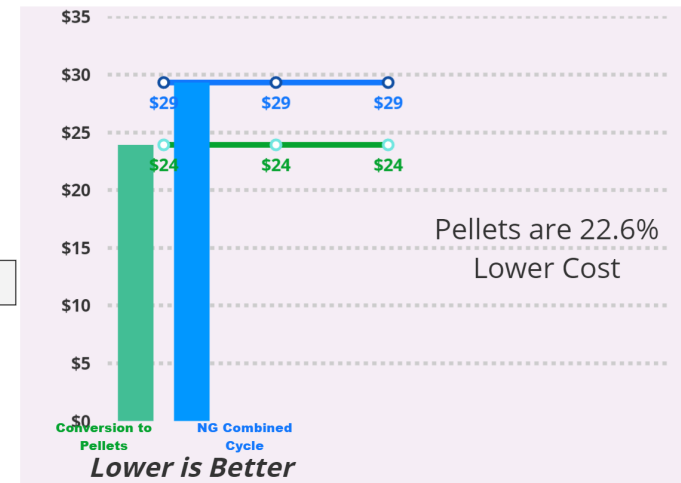
CO2 Emissions from Coal Combustion = 270 kgs CO2/GJ

CO2 Emissions from NG Combustion = 122 kgs CO2/GJ

Carbon Tax?

Consider Carbon Capture And Sequestration?

NPV of the Cost per Avoided Tonne of CO2



Pellets are 22.6% Percent Lower - Pellets Cost Less per Tonne of Avoided CO2 than NGCC

Figure 4 - Dashboard



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If the new NGCC plant is assumed to operate at a capacity factor greater than 80% and natural gas prices are assumed to remain below about \$3.30 per MMBTU, then the NGCC plant will deliver the lowest cost per avoided tonne of CO₂ emissions.

However, as the image on the preceding page shows, even with low NG prices, if the plant is expected to operate as a load-following generator behind baseload complimenting the increasing supply of wind and solar power, then under many plausible scenarios, the modified PC station delivers the lowest cost per avoided tonne of CO₂ emissions.

The reader is encouraged to open the interactive dashboard and experiment with different input assumptions.

Take particular note of the impact of changes in capacity factor. For power stations with lower capacity factors, such as peaking plants, the results are significantly more favorable for the pellet conversion scenario⁸. This is because as less fuel is used over the term of the analysis, the CAPEX becomes more dominant in the cost metrics. The CAPEX for the PC station conversion is significantly lower than the CAPEX for a new build NGCC station.

As has been proven by many coal-to-pellet conversions of power stations globally, there is no de-rating of the power station if the modifications that are included in the capital cost assumptions are properly implemented. Efficient coal power plants converted to use pellet fuel have the same efficiency and reliability after making modifications to the fuel handling and feed systems as they did when combusting coal.

The operating costs, due primarily to the higher cost per unit of energy for wood pellet fuel, are higher for the converted plants. That is why government policies with respect to the revenues of the generating entity are essential.

Policy Needs to Support the Least Costly Pathway to Decarbonizing the On-Demand Generation Mix

Decarbonization policies are necessary to address climate change. The best strategic plans should be broader than only including support for wind and solar generation and the essential massive energy storage capacity required for grid reliability and stability. Until energy storage becomes sufficient⁹ to buffer the variable and intermittent generation from wind and solar, baseload and peaking plants must exist.

⁸ See the recent FutureMetrics white paper a dashboard showing how advanced thermally treated water-resistant pellet fuel may be the optimal choice for low capacity factor stations. That paper and dashboard are on the [FutureMetrics website](#).

⁹ At best, at least a decade away (likely more). And there will always be long-tail instances when thermal generation will be required. As we move toward that day, capacity factors for thermal generators will fall further which supports the option (2) pathway.



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The current trend in the US of retiring coal fired power plants and building new high efficiency natural gas fired plants is rational if minimizing operating costs is the only decision metric and there is no benefit to minimizing carbon emissions.

However, if policymakers' primary goal is to lower carbon emissions, it makes better economic and environment sense to choose the pathway with the lowest total cost per avoided tonne of CO₂.

Showing how policy matters, below is another screenshot of the dashboard (Figure 5) showing a scenario with a 75% capacity factor, NG at \$2.00 per MMBTU, and pellet fuel at \$200 per tonne... and a carbon tax of \$75 per metric tonne of CO₂ emitted.

Even with low NG cost and higher pellet fuel cost, the converted PC station delivers a 91% lower cost per avoided tonne of CO₂.

Again, if the objective of policy is to find the lowest cost solution for supplying on-demand power and minimizing carbon dioxide emissions, converting existing PC stations is, to use a cliché, a “no brainer”.

Conclusion

Carbon reduction policy requires complementary **policy mechanisms to guide the markets toward the optimal solution in terms of the cost per avoided tonne**. Policy that forces the internalization of the external costs of pollution is well within the normal responsibility of government.

In any industrial sector, if left unregulated, industry defaults to the lowest production costs regardless of environmental impacts. That is why policy regulates emissions. The well-being of society, now and in the future, requires intervention.

As this paper and the accompanying dashboard have shown, when comparing NGCC and coal-to-pellet conversion, and when factoring in the reduction in CO₂ emissions from each, the strategy that provides significantly higher CO₂ reduction at a lower net monetary cost to society per tonne of CO₂ avoided is by repurposing existing PC power plants to run on industrial wood pellets.

If carbon capture and sequestration (CCS) is added, the pellet strategy can be even more compelling.

Use the dashboard that accompanies this white paper to see that happens if CCS is added for NG and for pellets¹⁰.

Note that this analysis does not take into consideration the impacts of methane (natural gas) leakage. Adding in the heat trapping impacts of unabated emissions of CH₄ will shift the results more in favor of option (2).

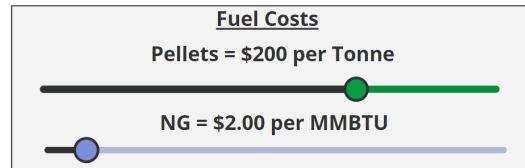
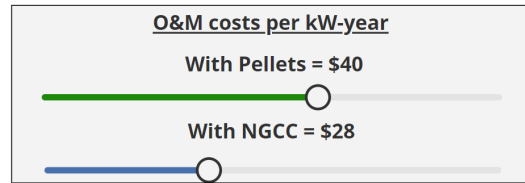
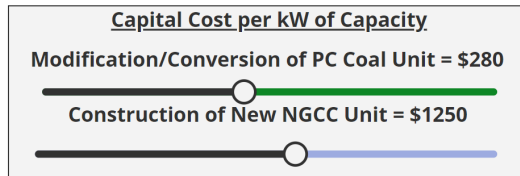
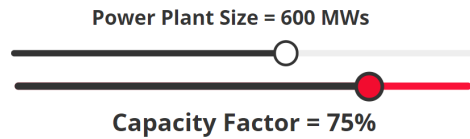
¹⁰ In the dashboard model, if CCS and a carbon tax are enabled, it is assumed that the negative emissions associated with bioenergy CCS (BECCS) are credited at the same rate as the carbon tax. That is, the power station using BECCS will receive payments for the captured and sequestered carbon dioxide.



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40.0% Coal or Pellet Power Plant Efficiency

53.0% NGCC Power Plant Efficiency

18.00 Pellets GJ per Tonne = 5.28 MWh

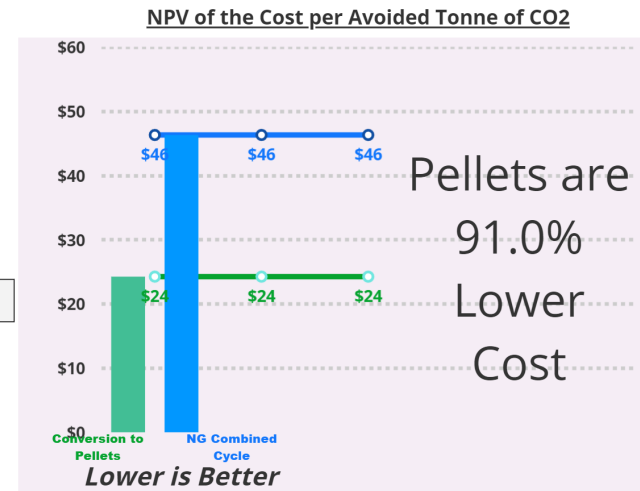
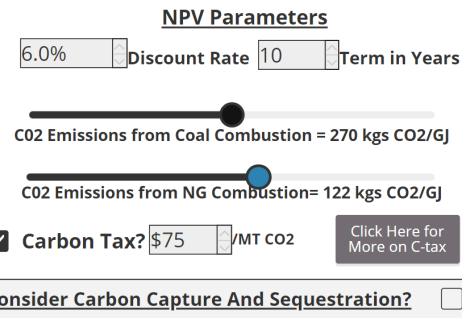
25.00 Coal GJ per Tonne = 7.33 MWh

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	Conversion to Pellets	Nat Gas Combined Cycle	Coal
Net Tonnes of CO2 Produced over 10 Years from Combustion	0 ?	54,012,129	158,383,929
Tonnes of CO2 Avoided over 10 Years	158,383,929	104,371,799	0
Percent Reduction vs. Coal	100.0%	65.9%	0%
NPV of Total Costs at a 6.0% Discount Rate over 10 Years	-\$3,843,424,758	-\$4,838,619,749	
NPV of the Cost per Avoided Tonne of CO2 ==>	\$24.27	\$46.36	



Pellets are 91.0% Percent Lower - Pellets Cost Less per Tonne of Avoided CO2 than NGCC

Figure 5 - Dashboard with Carbon Tax